Project Title: Block-level Yield Prediction for Seasonal N Fertilization Strategies in California's Almond Orchards

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Cooperator(s): Bruce Lampinen, Ted DeJong, Almond Farm Advisors, and 20 major almond growers from across California representing more than 60,000 acres, 500 blocks and an average of 7 years of data for each block.

Supporter(s): Almond Board of California, ESJWQC, SSJV MPEP, UC ANR California Institute for Water Resources, SureHarvest, LAND IQ, CERES Imaging

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B. Executive Summary

1. <u>Problem</u>

New legislatively mandated N management strategies for Almond requires growers to develop a pre-season N use program based on a Feb yield potential estimate and to update the estimate in May to establish seasonal N fertilization strategies. Accurately predicting yield in the early season is the missing link in the current N management plan and growers desperately need this capability. Historically, attempts to develop yield models have been limited by the inability of researchers to gain access to the needed historic block level yield data sets. Through collaboration with a large number of growers we have obtained access to long-term historic (3-12 years) and ongoing yield data for 60,000 acres of active production from across California. This data will allow for the first time, a realistic capacity to develop yield prediction models for Almond. With this data and a suite of additional public imagery and climatic data and integration of crop and bee models, we propose to develop a block-level yield prediction model and tools to assist growers in their adaptive nutrient management practices. Almond will be used as a model crop for this project as it is the largest tree industry with the best available database. The methods used will however, be extended to other tree crops in California. This project is designed to improve our ability to estimate the amount of N that will be removed (r) so that management practices can be adjusted to optimize applied N (a) and thus optimize a/r.

2. <u>Objectives, Approach, and Evaluation</u>

Project objectives: The goal is to develop a public yield prediction model that growers can use by including their own data and information in a private web session that interacts with the model but does not upload grower data to any public system. The underlying model will always remain a public tool managed by and licensed to UCD. This approach ensures model integrity while enabling public-private partnerships and ongoing development.

Our objectives are 1) Develop a cost-effective remote sensing tool to quantify canopy size, leaf and flower conditions and monitor environmental stressors; 2) Build data-driven statistical models for early-season yield projection and mid-season yield updates; 3) Create an interactive Yield Calculator app to provide end users with timely block-level almond yield estimate; and 4) Develop an effective outreach program.

Approach: Our modeling strategy leverages existing historic yield data from growers and takes advantages of geospatial data layers of biophysical, climate, and remote sensing based predictors. We have made agreements with 20 almond growers from across CA to access current and historic yield data. Collectively this represents 60,000 acres, 1,000's of individual block yield data points covering diverse orchard conditions and a significant proportion of the acreage in the SJV. We have obtained an agreement from CERES imaging to provide free historic imaging (80,000 acres) and low cost imaging of all blocks included in this project. Further, we have access to historic and current weather data from the CIMIS network, historic and current public medium to high resolution satellite imagery (LANDSAT) and soil data in the SoilWeb database, and an agreement with the Almond Board of California to access the statewide survey of all almond orchards (Joel Kimmelshue, LandIQ). This data will be integrated with knowledge of almond climatic response (Brown, Pope, Luedeling), crop canopy determinants of yield (Lampinen, DeJong, Saa, Zarate), bee and pollination biology (Lastro-Nino) to build, optimize and scale the yield prediction model from block to state. The integrated monitoring and modeling approach will use information from a large number of historic and current individual block yield data, existing models of chilling, flowering and bee behavior, and will capture the impacts of prior-season canopy and tree growth and spring conditions derived from satellite and aerial imagery. Models will then be built to best predict yield and these models will be validated against current yields reported by our collaborators.

We will build interactive, easy-to-use yield prediction tools and apps in desktops and mobile devices. The tool will automatically extract the predictors from the spatial and temporal data stored in the system, and then calculate block yield estimates in Feb and May using the calibrated models. The Yield Calculator stores data by orchard block, making updates easy. The system will also allow growers to enter actual yields that could be used iteratively to improve models. The yield tools will be coupled with the N Calculator to guide N management. We will work with stakeholders through regular meetings, workshops, and field days to collect their feedback and perspectives and to extend the findings. The model will be designed to allow users to contrast predicted with realized yield so that the model will be iteratively improved.

Evaluation: The primary outcome of the current project is a strategy and associated tools to provide accurate yield estimation. To ensure that the project meets the proposed goals, we will implement the following performance measures: 1) comparing the potential yield predicted by average farmers with the predictions from the models/tools developed by this project and final measured yield, 2) documenting increased N use efficiency through survey tools currently operated by the Almond Board Sustainability Initiative, 3) identifying areas with low productivity in contrast to orchards in similar environmental conditions, and 4) presenting results to growers via UC Almond workshops and field days and to research communities through conferences and peer-reviewed publications. Benchmark is improved yield estimate and thus optimized N use compared to other regional growers without sacrificing yield. Targets include increased growers' security and profitability by reduced N demand and use and sustainability through compliance with new mandates. To ensure the project is extended we have partnered with Almond Board (LOS) and Water Coalitions LOS) to provide written, online, electronic and workshop extension and demonstration.

3. <u>Audience</u>

All almond producers, consultants and water coalitions and all individuals for whom a yield prediction model is of value. The yield prediction tools will assist growers to manage N adaptively, comply with mandated requirements, and ensure industry sustainability. The outcome will be used in N management programs that require pre-season yield prediction and in-season yield adjustment and will immediately be used to increase the utility of the widely used online Almond Board of California Nitrogen Management tool. For example, CCAs, PCAs, extension, and other agricultural professionals will use the tools developed by this project to make data-driven nutrient recommendations for Almond in California.

This project focuses on block (management unit) yield prediction to estimate crop removal rates (r) to optimize N application rate (a). This is the N management approach and intensity that is mandated under ILRP Orders. This project will also help develop tools that can be used to contrast performance of similar production units across regions with the goal of identifying the best practices and outcomes. This will directly benefit the MPEP program.

C. Justification

1. <u>Problem</u>

California's almond acreage is 940,000 acres with a total value of $5.8 billion in 2014. Due to its scale, N management in almond has a large potential impact on CA groundwater quality and a failure to reduce N levels in groundwater threatens the viability of the specialty industry. New legislatively mandated N management strategies for Almond, requires growers to develop a nitrogen budget for the year based upon February yield potential estimate and to update the estimate in May to establish seasonal N fertilization strategies. N planning in almonds requires both yield estimation and measurement of N inputs. While highly skilled growers can estimate yield with accuracy, most growers have neither the skill nor time to do so. Accurately predicting yield in the early season is thus the missing link in the current N management plan and growers desperately need this capability.

Growers and researchers are aware that almond yield varies by year and by location with some regions and locations having consistently better yield than others even in orchards of similar age, management practice and planting strategy. The biological, management and biophysical factors that underlie these yield differences are not well understood and have never been systematically characterized. The development of a database of location specific historic yields, and a yield model to characterize past performance and predict future performance will allow researchers to query the causes and effects of location and year on productivity and to test current theories of the determinant of yields. Questions such as the effect of soil type or water source on productivity, the influence of flowering environment on bee activity, the role of prior year yield on future yield, the ideal cultivar mixes for specific locations, the effect of spring or summer climate on current and future yield and many other questions of interest can be envisioned. A tool/model that can predict block level yield is therefore needed by growers and researchers.

This project is timely as new N rules are being imposed in 2016 and 2017. It will provide block-level yield estimates to strengthen the recently developed N management tools (CDFA and ABC funded). The ability to predict yield provides individual growers with information required to manage inputs and resources, to schedule on-farm activities and to manage harvest and marketing agreements.

2. <u>FREP Mission and Research Priorities</u>

This project fits well within FREP's Priority Research Areas in "***Developing Integrated Water and Nutrient Management Tools" and "Education and Outreach"***, as it fills a critical gap in the adoption and implementation of the mandated N management strategies now required by water coalitions and water boards. It capitalizes on our unprecedented access to historic yield data from many growers, biophysical, climate, and remote sensing data. Almond growers face the challenge of intensifying production while protecting groundwater quality from nitrate excess. Accurate block-level yield prediction and mid-season adjustment will help almond growers estimate N demand throughout growth stages, and thus provides a practical strategy to minimize N input while maximizing productivity. This project will enhance the previously developed yield-driven N fertilization protocol and N calculator to assist growers as they integrate new regulations into farming operations. The outcome will also benefit the state by enhancing nutrient use efficiency and groundwater quality, and thus directly contribute to FREP's mission of advancing the environmentally safe and agronomically sound use of fertilizing materials.

3. <u>Impact</u>

This project will directly benefit all almond growers (7,200), and their Crop Advisors and Pest control advisors (800) and associated nutrient and service industries by improving the ability of growers to estimate yields and prescribe effective and efficient N management plans. This research has the potential to reduce N loading into groundwater of California and thereby benefit the estimated 250,000 individuals who live in regions of California with contaminated drinking water (Harter Report). This project will provide researchers and growers with an improved understanding of the determinants of yield in Almond, which will be critical in the development of improved sustainability practices. Almond is a 5.8 billion dollar industry; the viability of the industry is dependent upon the ability to maintain sustainable production practices.

We will focus on Almond as the largest nut tree industry in California, however the models developed and the methodology used will serve as a template for model development in other tree crops (Walnut, Pistachio, Citrus etc.). The ability to predict yield provides individual growers with information required to manage inputs and resources, to schedule on-farm activities and to manage harvest and marketing agreements. The ability to predict yield at a regional and statewide basis (in collaboration with recent statewide orchard assessment) will assist the industry as a whole with marketing and other planning needs.

This project has significant potential to serve as an engine for the development of the remote sensing, field monitoring strategies and precision agricultural industries. This will be achieved by developing a public good (the yield estimation model) utilizing public remote sensing and climate models coupled with a database of anonymous grower yield records. The foundation developed will allow private companies to expand and personalize offerings to individual growers, service and goods providers.

4. Long-Term Solutions.

This project will be well positioned to attract additional funding from the Almond Board, the Water Coalitions, Water Quality Control Boards of California, and the California Institute of Water Resources as they continue to address the challenges of N contamination of groundwater. Once the monitoring and prediction system is developed and validated, we will leverage interest and additional funds from large farm operations and private industry in their efforts to minimize their own N pollution and optimize production. There is considerable commercial interest in the ability to predict yield and identify production constraints effectively and as a consequence the models and information developed in this project will encourage new technologies and services for growers.

By having the underlying fundamental models held at a public institution, we will provide the legitimacy and standards that the remote sensing and precision agriculture industries are currently lacking as they attempt to build strategies and products to serve Californian agriculture. In the long term we see this effort as providing the UC legitimized approach to the modeling strategy and application of remote sensing, modeling and precision N management strategies for use by growers, consultants and private industry to further adapt and optimize for their stakeholders. As a consequence there will be ongoing opportunities for further development, optimization and improvement of the models. Given the developing nature of the ILRP and MPEP programs over the next 5-10 years it appears quite certain that the success of this project will generate many future opportunities. However, even in the absence of future funding the underlying models and the approaches developed will be of long-term value and a critical component for development in this realm.

5. Related Research.

Our team of UC AES faculty, CE specialists, and farm advisors will work together to develop a data-driven yield prediction tool and grower/researcher interface for yield prediction. This project will draw upon the team's previous experience on N budget model, pomology and management tools (Brown, Saa et al. (2014), Muhammad et al. (2015)), remote sensing and modeling (Jin) and bee biology (Lastro Nino). In particular, it builds on completed research and almond, pistachio and walnut physiological modeling activities designed to help predict flowering date and climate change impact conducted in the Specialty Crop Block Grant (SCB09044: Brown). The proposed project will utilize the previously developed physiological component and further enhance them with crop monitoring and modeling activities using satellite and aerial imagery. The proposed project has a very different goal of yield prediction to optimize fertilizer management, which has never been previously attempted at an individual block scale.

7. <u>Grower Use.</u>

The a/r ratio is the most fundamental and tangible metric that growers will be using to meet to ILRP mandated N management reporting. The quality of the a/r metric depends to a very large extent on the ability to predict yield with some degree of certainty. Currently, the majority of growers do not feel they can anticipate (r) with any degree of certainty and hence they cannot manage N fertilization (a) with sufficient certainty. The success of this project will be of great value to growers.

In addition, the modeling approach that we will use will provides a means to contrast performance and N use of almond production units across similar and dissimilar growing conditions, management strategies, irrigation strategies, soils etc. This ability to contrast performance and efficiency will allow us to model the larger scale determinants of yield, N use efficiency and productivity. This will be of great value to growers, researchers and industry. As the demands for growers to improve a/r iteratively over time there will be an increasing demand for precision farming strategies. The current project strives to identify these opportunities and provide the framework and scientific basis for future development in this arena.

D. Objectives

- Develop a cost-effective remote sensing toolkit to characterize orchards for their yield potential.
- Build data-driven statistical models for early-season yield projection and mid-season yield updates by using remote sensing based predictors, local climate and environmental data, a large database of block level historic yields, and knowledge of the biological determinants of yield in almond (chilling, light interception, bee flight models etc).
- Create an interactive *Yield Calculator* app to provide end users with timely block-level almond yield estimate for resource management decisions and for integration with other data inputs and commercial decision support providers (imagery companies, soil and water sensing companies, irrigation management, etc.)
- Couple with N Management Interface and Outreach and develop an effective outreach program to collect feedback and disseminate the outcomes.

E. Work Plans and Methods

The overall approach to developing a block specific yield prediction model is to 1) Collect historical and current records of yield, orchard characteristics and location from a large number of geographically diverse almond blocks, 2) To download and overlay free and commercial satellite and aerial imagery and free soils and climate data from these block locations, 3) To utilize a statistical modeling strategy and biological expertise to develop a block specific yield model. The project team will work together to perform specific tasks following the timeline as listed below:

1. Work Plan

Year 1 Tasks and Activities	Timeline
T1. Literature review (Brown, Jin, Nino) T1a. A thorough review will be done to gather information on what key biological, environmental, and management factors are, and how they affect almond yield, such as tree age, canopy cover, irrigation and nitrogen management and bloom characteristics. T1b. We will review existing statistical and biophysical yield models, and their capabilities and limitations for fertilization planning.	Jan-Apr 2017
T2. Explore data encryption and privacy protocol (Brown, Jin) To encourage more growers to share their yield data, we have established and will continue to refine a robust legally protected data sharing protocol (with UCD Campus Council). We will continue to review data privacy issue and keep exploring various options to protect data privacy.	Jan-Jun 2017
T3. Collect data of yield determinants (Jin)	Jan. – Aug.
T3a. Assemble existing free remote sensing data such as Landsat, MODIS, VIIRS, and NAIP, Rapid Eye via Open California, up to 2016, and other geospatial layers of orchards such as tree age from LAND IQ.	Jan-Mar 2017
T3b. Compile weather, climate record and soil geospatial layers.	Jan-Mar,
T3c. Field measurements of canopy, leaf, bloom metrics and bee activity.	Feb-Mar
T3d. Acquire high-resolution multispectral and thermal aerial imagery via CERES Imaging.	Feb-Mar, Jul
T4. Collect and compile block-level yield data (Brown) We have received pledges to share yield records from the individual production units of 20 major almond growers representing more than 60,000 acres of almond production. Additional cooperators may also join this consortium. We will follow the data privacy protocol and assemble these data under agreements of cooperation established with every grower to satisfy their unique privacy agreements.	Jan–Nov 2017
T5. Develop remote sensing tools (Jin)	
5a. Develop bloom indices based on remote sensing data at multiple spatial scales and field measurements.	Feb – Aug 2017
5b. Develop remote sensing algorithms to characterize orchard characteristics and canopy attributes including leaf out for yield potential	Jan - June
5c. Validate remote sensing algorithms and tools with ground truth	Aug – Dec
T6. Develop yield prediction models (Jin, Brown, Nino) Tiered models from simplest to sophisticated models will be developed and tested for applications with various levels of input data.	Apr – Dec 2017
6a. Bee foraging activity analysis and modeling (Nino) Data on bee foraging activity and environmental parameters influencing bee foraging activity, collected during blooming seasons, will be used to model bee activity based upon flowering environmental conditions.	Mar – Sep 2017
6b. Develop tiered models for early season yield prediction (Brown) Advanced statistical methods will be used to develop effective and robust pre-season yield potential models in February, based on the statistical relationships of the yield potential with historic block yields, tree age,	Apr – Sep 2017

prior season canopy attributes, and prior season weather.	
6c. Build and test tiered models for mid-season adjustment (Jin) Emerging conditions such as spring flower and leaf out data, in-season drought/heat/salinity, and other stressors will be derived from aerial imagery, and integrated with weather and bee activity data to develop mid-season yield adjustment models.	June – Dec 2017
6d. Validation and accuracy assessment of yield prediction models (All) 70% of spatial data will be randomly selected for model development, and the rest of data will be used to assess the model performance.	Nov – Dec 2017
T7. Outreach (All) We will work closely with farm advisers, SureHarvest, and growers to collect their feedback and perspectives and communicate initial results.	June – Dec 2017
7a. Meet growers and participate Field Day to gather input and data needs	June 2017
7b. Present results at UC ANR short course and gather feedback	Sep – Nov
7c. Present results at Almond Conference	Dec 2017

Year 2 Tasks and Activities	Timeline
T1. Refine data encryption and privacy protection method (Brown) We will continue to work with UCD Campus Council to enhance data privacy protection protocol for block yield data protect.	Jan – Mar 2018
T2. Collect data of yield determinants for current year (Jin)	Jan - May
T2a. Continue to assemble all 2017 remote sensing and weather data.	Jan - Feb
T2b. Field measurements of canopy, leaf, bloom metrics and bee activity.	Feb-Mar
T2c. Acquire high-resolution aerial imagery during bloom season.	Feb-Mar
T3. Collect prior year block-level yield data (Brown)	Jan - Dec
T4. Refine remote sensing tools (Jin)	Mar - Sep
T4a. Refine bloom indices and canopy attributes with current year data	Mar - June
T4b. Blend remote sensing data from multiple sources to develop tools for characterizing orchard, canopy, leaf, and flower information.	May-Nov
T4c. Validation of remote sensing algorithms and tools	Feb - Sep
T5. Refine and validate yield prediction models (All)	Mar - Oct 2018
5a. Refine bee foraging activity analysis and modeling	
5b. Preliminary models for both early season and mid-season yield prediction will be further assessed and refined with new data.	
5c. Validation of yield prediction model with new data	
T6. Develop Almond Yield Calculator app and tools (Jin, Brown)	Jun-Dec 2018
T6a. We will create an interactive *Yield Calculator* app to provide end users with timely block-level almond yield estimate for resource management decisions and for integration with other data inputs and commercial decision support providers (imagery companies, soil and water sensing companies, irrigation management, etc.)	
T6b. Test *Yield Calculator* app performance	
T7. Outreach and publish findings in journals (All)	
7a. Meet growers, farm advisors, and Water Coalitions to gather feedbacks	Feb-Aug

7b. Present results at Almond Conference and other workshops	Jun- Dec 2018
7c. Publish and disseminate findings via UC extension, trade journals, blogs, and scientific publications	

Year 3 Tasks and Deliverables	Timeline
T1. Collect most recent yield and yield determinants (Brown, Jin)	Jan-May 2019
T1a. Continue to collect 2018 block yield data, compile free 2018 remote sensing and weather record, and acquire aerial imagery.	
T1b. Deliverable: a spatial database of factors affecting yields including static soil layers and annual updated layers such as canopy attributes	Jun
T2. Validate and deliver remote sensing tools (Jin) Deliverable: open-source remote sensing tools	Apr
T3. Refine and validate yield prediction models (Brown, Jin) Deliverable: open source tiered yield models available online	Jun
T4. Refine and finalize Almond Yield Calculator app and tools Deliverable: Yield Calculator app and tools available online	Jun
T5. Integrate with N Calculator and test performance (Brown) Deliverable: Yield Calculator fully integrated with N Calculator	Sep
T6. Present and publish findings (All)	May-Dec 2019
5a. Organize a workshop to disseminate the findings and tools to Almond stakeholders	
5b. Develop webinars and user's guide for app use	
5c. Present results at workshops and conferences	
Deliverables: Multimedia documents and reports, publications	

2. Methods

2.1. Collecting data of historic block yield and yield determinants

2.1.1 Remote sensing imagery for biophysical estimate

We will collect a variety of freely available satellite imagery and, aerial imagery provided by our collaborator (CERES) to quantify canopy size, leaf and flower conditions and monitor environmental stressors. CERES Imaging will acquire multispectral imagery at 25cm resolution in the visible and near infrared spectrum, which allows for quantifying vegetation indices, canopy size, leaf area index, and bloom conditions at high spatial resolution. We will also blend multispectral Landsat imagery every 16 day at 30m resolution, Sentinel-2, and MODIS/VIIRS imagery every day at 250m to track the dynamics of leaf and flower conditions at larger scales. Bloom and early season leaf out patterns are of particular interest as these attributes integrate canopy size, prior years yield, tree vigor, winter and spring climate. Other emerging conditions such as in-season drought/heat/salinity and other stressors will also be derived using various indices from remote sensing imagery as a surrogate.

We will develop special bloom indices by combining the multi-spectral remote sensing measurements to correlate with ground measured bloom intensity and bloom overlap conditions. While it has not been rigorously tested as a means of yield prediction, imagery of bloom intensity and bloom overlap can be readily acquired and has great promise as an integrative determinant of yield potential and is a critical parameter used by grower experts to estimate yield in the field. Bloom intensity integrates tree health, vigor, tree area, climate conditions prior to and during bloom, bloom overlap and orchard history. The potential to utilize aerial imagery (satellite, fixed wing or drone) to rapidly estimate yield potential has not been explored. Gaining access to sufficient images at each site at multiple times during the bloom period will require an integration of multiple imagery sources to which we will have access. All remote sensing algorithms will be validated with ground truthing data and uncertainties will be quantified. The automated tools will then be developed to pre-process imagery and derive the key indicators of yield potential near real-time, which will be plugged into the model in a timely fashion.

2.1.2. *Collecting data of yield determinants*

The ability of a skilled individual to predict yield demonstrates that there are a series of biophysical cues (leaf area, tree vigor, tree age, tree health, bloom intensity and others), reference information (historical and comparative yields) and environmental factors (water availability and quality, nutrition, local climatic conditions, bee foraging activity, etc.) that could be used to generate a statistical and biophysical model to predict yield for individual blocks. In addition to the remote sensing based biophysical estimate, we will use station and spatial CIMIS weather data and PRISM past climate data as well. Spatial layers of soil property will be extracted from California Soil Resources Lab. Furthermore, the growth models developed by Ted DeJong as well as knowledge of the role of flower number on yield potential (DeJong et al in press) and modeled carbon budgets all contribute knowledge that can be integrated into a yield prediction model that will not rely upon, and can improve upon, expert real-time human observation. We will also acquire spatial maps of state-wide almond orchard blocks, orchard ages, and many other attributes over the past 5 years, and any future updates, provided by our collaborator LAND IQ (ABC funded) for free. This will allow us to scale our approach to all almond orchards across the state.

2.1.3. Establishing data privacy protection protocol and assembling historic block yield and management data

The final and perhaps most critical component required for the generation and validation of a yield prediction model is the availability of a database of yield records drawn from a wide diversity of almond orchards. *We have received pledges to share such data from the individual production units of 20 major almond growers representing more than 60,000 acres of almond production throughout the major growing regions of California.* Growers will also provide information on cultivars, planting density, orchard age, overall management practices including historical tissue nutrient analyses and any known constraints, e.g., water limitations in a given year etc. Additional cooperators may also join this consortium. This represents as many as 500 individual production blocks, each with 2-30 years of records for each block for a total of >3,000 block x year data points.

To encourage growers to share their yield data, which is typically a significant impediment, we have established a robust legally protected data sharing protocol (with Kristen Stevensen, UCD Campus Council). Following data input we would apply a technique to decouple the plot-landowner relationship, by ‘fuzzing’ or ‘swapping’ the block coordinates based on the similarity of the ‘ecological signal’ among the blocks. These procedures will preserve privacy while maintaining the spatial nature of the block almond yield data for the development and validation of the yield models. The same anonymity will be implemented for the final grower interface. Agreements of cooperation will be established with every grower to satisfy their unique privacy requirements.

2.2. Building data-driven statistical yield prediction models

We will use advanced statistical methods, including data mining approaches, to develop effective and robust models to predict the yield potential in February and adjust it in May. Tiered models from simplest to sophisticated models will be developed for applications with various levels of input data. The separation of model activities into two phases will allow ample time for model integration of bloom and subsequent spring climate data.

2.2.1 Pre-season yield potential model

We will analyze the collected data at the block level and derive the statistical relationships of the yield potential with historic block yields, tree age, prior season canopy attributes derived from remote sensing data, and prior season weather. A suite of climate variables will be explored as the predictors, including growing degree days (GDD), chilling , fog, frost, accumulated degree-days, the sum of all previous degree-days from a given date. Data over the preceding two year and the current year will be included.

With the large collection of plot yield data for a wide diversity of locations, cultivar mixes and orchard composition, machine learning algorithms will be used to classify and mine the data, and simple models will be developed to estimate yield potential for given classes of orchards, based on some key predictors such as tree age, soil properties, and cultivar mixes (e.g., NorthEastern SJV, sandy loam, 12-15 years old, 50%NP 50% Monterrey). Much of this work can be performed with historical data, prior to the initial bloom imagery. For more accurate yield prediction, block specific canopy attributes from previous imagery, climate, and other information will be integrated for statistical model development and prediction.

2.2.2 Analyzing and modeling bee foraging activity

Bee activity is another crucial determinant of the final nut yield. Bee activity will be modeled based upon environmental conditions during flowering in collaboration with Dr. Elina L. Niño, a bee biologist at UCD. Successful pollination in almond depends on the presence of pollinators in almond orchards, and on high foraging activity. Foraging activity is dependent on environmental temperature, solar radiation, wind speed, and other weather parameters, as well as hive placement within an orchard, hive density in a given area and hive strength. While data exist showing the effects of various environmental and colony factors on foraging intensity, amount of pollen collected and pollination studies directly correlating these factors with pollination success, nut set and nut yield are scarce. We will gather data on various environmental parameters influencing bee foraging activity during three almond blooming seasons in multiple orchards throughout California. We will correlate the final nut yield of individual blocks/orchards/zones with the environmental and colony factors in the context of the larger yield prediction model. The degree of the bee foraging activity will be recorded as the bees are leaving the hive and in the almond trees. Bee activity will be correlated with the measured environmental data of temperature, humidity, wind speed, and cloud coverage. In addition, we will track hive strength and hive position in relation to the orchard which can also heavily influence pollination success. Data will be correlated with the final nut yield in order to validate the yield prediction model.

2.2.3 Developing mid-season yield prediction model

For mid-season yield adjustment, we will derive emerging conditions at flower and leaf emergence such as spring flower and leaf out data, in-season drought/heat/salinity and other stressors using remotely sensed imagery as a surrogate, using the remote sensing tools that we develop and validate with ground truthing data from this project. Bloom imagery and early season leaf out patterns are of particular interest as it integrates attributes of canopy size, prior years yield, tree vigor, winter and spring climate.

These conditions of flower and leaf emergence will be integrated with bee activity/pollination data and weather data for statistical model development to adjust the pre-season yield potential estimate in May. Light interception, growing season length, and climate variables, including accumulated degree-days from a given date and within a specific phenological stage, fog and frost will be explored as additional predictors.

2.2.4. Validating yield prediction models

We will randomly select 70% of spatial data for training and modeling development. To assess the model performance, the modeling process will include an annual validation against a subset (30%) of actual yield data provided by collaborators, at the completion of the first and subsequent years of the project, in addition to in-field sampling and imagery and bee flight analysis. Spatial maps of state-wide almond orchard blocks, orchard ages, and many other attributes, provided by our collaborator LAND IQ, will allow us to scale our approach to all almond orchards across the state. The synergistic use of block yield data, remote sensing "big data", and advanced data mining approach will enable us to estimate yield more efficiently and accurately, and advance our mechanistic understanding of the relationships between yield, climate, N, canopy conditions, and spatially varying environmental drivers.

2.3. Developing Grower's Yield Prediction Interface

Once calibrated with a statewide sampling dataset of block yield, the yield models can be used to estimate both historic and current early-season and in-season almond yield. To enhance data access and facilitate the adoption of the yield prediction model, we will build an interactive, easy-to-use online tool for both desktops and mobile devices, similar to the widely used Nitrogen Calculator http://www.almonds.com/nutrients#tc-calculator. Once the block location is entered, the tool will automatically extract the predictors from the spatial and temporal data stored in the system, and the users have the option to modify the orchard configuration and previous yield data based on their own knowledge. Using the pre- and in-season yield prediction models, the tool will then select the appropriate level of tiered models, depending on the availability of input data, and calculate block yield estimates in February and May.

To ensure data privacy it is envisioned that the Yield Calculator would store grower data on the local computer by orchard block, making updates easy as information changes but maintaining data privacy. The online mapping and spatial query will allow the users to visualize time series of block level yield data and the associated predictor, quantitatively compare it with the historical long term mean or upper or lower bounds of production, and thus facilitate adaptive management based on emerging conditions and prediction. This tool will also help the stakeholders to examine the spatial heterogeneity within and across the management units and thus identify the most vulnerable areas. This system would also allow growers to enter actual yields at the end of year that could be used iteratively to improve model.

2.4. Couple with N Management Interface and Outreach

The monitoring and modeling tools will be coupled with N Calculator to guide the block-level N management. Throughout the project the team will work in close cooperation with farm advisers, SureHarvest, and growers through regular meetings, workshops, and field days to collect their feedback and perspectives and to demonstrate and discuss the findings. The project outcomes will be also communicated to the Almond Board, and disseminated through UC extension, webinars, and scientific publications.

The Almond Board of California (ABC) and Blue Diamond Growers (BDG), represent 95% of all almond producers and are partners and supporters of this activity. The project outcome will immediately be used to increase the utility of the free online ABC Nitrogen Management tool. The ABC will maintain and update the mobile/tablet Apps and online tools developed here free of charge (LOS). The ABC and BDG will promote this tool in their publications, newsletter and presentations (LOS). Two key Water Coalitions will incorporate this tool into N management updates and MPEP programs (LOS). In collaboration with the Almond Board, the yield prediction model will be integrated into the free Almond Board Sustainability (CASP) site that is already routinely used to manage 45% of all almond acreage (LOS). Specifically the yield prediction model results will be programmed to automatically populate the existing N management software on the CASP site. Dr. Brown will incorporate the model into training programs for Crop Consultants, who provide signatory authority on N management worksheets (LOS). The coordinating PCA/CCA association (CAPCA) will provide the information to all members. This model will also be incorporated into sites such as the CDFA-FREP Nutrient Management site. Drs. Brown and Jin will present information at industry and academic meetings and legislative hearings.

The developed model will be of great utility to researchers to query the model and database to derive the factors that constrain yield. For example, the model could be constrained to the top 10% of historic producing orchards across California with the assumption that these orchards had optimal management practices and no significant resource limitation. With these constraints, any remaining difference in productivity between orchards could then be examined to determine the underlying climatic or biophysical causes that constrain yield across different regions of California.

3. Experimental Site

Data will be collected from our partner growers situated across the entire Californian Almond growing region. Our grower partners represent the most progressive growers in the industry and as such the resultant data will be highly relevant and applicable.

F. Project Management, Evaluation, and Outreach

1. Management

The interdisciplinary team will provide the broad cross-section of expertise needed for this project. Dr. Brown will be the primary project liaison and co-director and will provide guidance and interpretation of all information related to the physiological and agronomic issues of N use and management practices. Dr. Jin is the project co-director and GIS, remote sensing and modeling coordinator. Dr. Elina L. Niño is a bee biologist and modeler who will lead the analysis and interpretation of bee related data and modeling and will contribute to integration and interpretation of bee activity and pollination information.

A bi-weekly project meeting will be established for all members including postdocs and project scientist involved in this project to report findings, exchange ideas, identify gaps, and form the direction of the research.

2. Evaluation

The primary outcome of the current project is a strategy and associated tools to provide accurate yield estimation. To ensure that the project meets the proposed goals, we will implement the following performance measures: 1) comparing the potential yield predicted by average farmers with the predictions from the models/tools developed by this project and final measured yield, 2) documenting increased N use efficiency through survey tools currently operated by the Almond Board Sustainability Initiative), 3) identifying areas with low productivity in contrast to orchards in similar environmental conditions, and 4) presenting results to growers via UC Almond workshops and field days and to research communities through conferences and peer-reviewed publications. Benchmark is improved yield estimate and thus optimized N use compared to other regional growers without sacrificing yield. Targets include increased growers' security and profitability by reduced N demand and use and sustainability through compliance with new mandates. To ensure the project is extended we have partnered with Almond Board (LOS) and Water Coalitions (LOS) to provide written, online, electroninc and workshop extension and demonstration.

Given the legislative mandated adoption of the a/r ratio and the adoption of this formula based on Dr. Brown's prior contributions it is expected that the yield estimation procedures developed in this proposal will be widely adopted. It can be expected that the implementation of improved N management will reduce industry-wide N usage by improving N use efficiency. Given the scale of almond acreage (800,000 acres) and N usage in the range of 225-275 lbs N, even a trivial savings of 10 lbs N acre over 800,000 acres represents 8,000,000 lbs of saved N each year. Urea N is currently priced at about $0.50 lb, representing a $4 million annual N savings and improved compliance with N regulations.

The nitrogen management guidelines adopted by the Water Board of California and mandated for all growers utilize an applied over removed nitrogen ratio (a/r) as the primary measure of good management practice and compliance with the Irrigated Lands Regulatory Program. The removal ratio is calculated as lbs of reported marketable yield x 68 lbs N, an approach that is directly derived from research funded by the PI on the grant (Brown). Since N is applied in the 7 month period prior to harvest, growers must utilize a yield estimation protocol to estimate and adjust N fertilization during the season. Accurate yield estimation is essential if N is to be managed efficiently and yield is to be maximized. The primary outcome of the current project is a strategy and associated tools to provide accurate yield estimation.

3. Outreach

We will develop an effective outreach program to collect feedback and disseminate the outcomes. Outreach activities include field days, workshop, presentations and multi-media publications for different stakeholder audiences including researchers, regulators, industry representatives and growers. In December 2017 and 2018, we will give oral and poster presentations at the Almond Conference hosted by the Almond Board of California. In February 2018 and 2019, we will provide an update of our research findings during ongoing N management trainings for certified crop advisors funded by a grant awarded to the UCANR Water Institute by FREP. During 2017, 2018 and 2019, we will author a research update for publication in grower magazines and the 'Almond Doctor' blog. In March 2019, we will give a talk about the results of our study at the Western Nutrient Management Conference held in Reno, NV and by April 2019, will submit research articles to the peer-reviewed scientific publications. In addition Dr. Brown is a member of the MPEP Technical Advisory Committee and serves as a scientific advisor to three Water Coalitions representing the majority of Californian almond production and is a *very* frequent speaker at industry (CPS, Helena, Agrium etc. WPHA, FREP, CCA/PCA) and commodity/Scientific (Almond, Pistachio, Walnut, Cal ASA) and extension (UCANR/County) meetings and in any given year can be expected to present 5-12 presentations on N management in Almond.

G. Budget Narrative

Total Requested Funding **$222,077** covers the cost relevant to Personnel, Fringe Benefits, Travel and Other expenses, from January 1, 2017 through December 31, 2019.

a) PERSONNEL ($157,187)

Starting salaries and Benefits are based on Fiscal Year 2017 rates and assume a 3% increase in each subsequent fiscal year.

<u>Salary and Wages:</u> $131,020

- Assistant Professor: $4,957 Salary support is requested for Dr. Yufang Jin whose effort will be 4% FTE for Year 1. Her annual base salary is $118,545.
- Postdoc Researcher (TBD): $114,555 A postdoctoral researcher at Level II will be employed (at 75% FTE) with starting annual salary of $47,268 for years 1, 2, and 3. The postdoc will work with Dr. Jin on remote sensing techniques and also on yield model development with Drs. Brown and Jin.
- Project Scientist (TBD): $11,508 A project scientist, with an annual salary of $53,900, will also be supported for 3%, 8%, and 8% FTE to develop website, Yield Calculator apps, and online tools in Years1, 2 and 3 respectively.

<u>Fringe Benefits:</u> $26,167 Composite benefit costs are expected to be i) $858 for *Dr. Jin* at the benefit rates of 17.3% for 2017; ii) $20,689 for the *Postdoc Scholar* at composite rates of 17.3%, 18.3% and 18.8% for 2017, 2018, and 2019; and iii) $4,620 for *Project Scientist* at the projected composite rates are 38.3%, 39.4% and 40.6% for 2017, 2018, and 2019.

b) OPERATING EXPENSES ($25,594)

<u>Travel :</u> $9,694 A total of ~17 multiple-day trips, located mostly across Central Valley in Fresno, Tulare, Kings, Madera, Stanislaus, Yuba, Colusa Counties during the project duration, on average ~550 miles per trip, for field measurements and outreach. **i)** Daily trips for one person to meet growers and participate annual Almond Field Day each year *($282 per trip per person*); **ii)** 2-day trips for two people to 2 field sites for field measurements for Years 1 and 2 *($2,187 per year*); **iii)** 2-day trips to present at UC ANR training by Dr. Brown each year *($342 per trip*); **iv)** Trips to annual 3-day Almond Conference in Sacramento for 2 person each year *($360 per trip*); **v)** 2-day trip to the Western Nutrient Management Conference to be held in Reno, in 2019 ($500); **vi)** Daily trips to speak to Water Coalitions, commodity industries by Dr. Brown during each project year ($282 per trip).

<u>Other Expenses:</u> $15,900 i) ***Contractor: CERES Imaging: $9,500*** This project will contract CERES Imaging to airborne multispectral and thermal imagery over selected almond orchards. Given the complexity of the task (involving personnel, fringe benefits, use of facilities and equipment, hardware and licensed software, ground transportation, insurance, maintenance and others), the contractor could not provide the cost of service on the basis of hourly rate and estimated number of hours, but instead provides aerial imagery with a total amount cost of $5,000, $3000, and $1500 for each of 3 years. It also provides free access to existing databanks of aerial imagery, representing 150,000 acres of coverage over the past 2 years (LOS). **ii)** ***Publication Cost: $6,000*** We plan to publish at least one, three, and four peer-reviewed high impact journal articles to share and disseminate our findings and tools with both research community and stakeholders, respectively, in project years 1, 2, and 3. An estimated $1,000 of publication fee per article is based on the current publication fees of the major production, nutrient/water related peer-reviewed journals. **iii)** ***Workshop Fee: $400*** is requested to rent a conference room for a training workshop to be organized and held at UC Davis Conference center at the end of the project (Year 3).

c) INDIRECT COSTS ($39,296)

Indirect costs have been calculated at the AB20 Approved rate of 25% Modified Total Direct Cost (MTDC), applied to the total direct cost of Personnel (Salaries & Wages: $131,020 + Fringe Benefits: $26,167)= $157,187x 25% = $39,296